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New 100 mm Gun Assembly Installation at Lawrence Livermore National Laboratory High Explosives Applications Facility

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NEW 100 mm GUN ASSEMBLY INSTALLATION AT LAWRENCE LIVERMORE NATIONAL LABORATORY HIGH EXPLOSIVES APPLICATIONS FACILITY

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Summary—A new 100mm gun assembly was recently installed and tested at Lawrence Livermore National Laboratories located in the High Explosives Applications Facility (HEAF). Thiot Ingenierie performed the design of the replacement barrel, based on improvements to the initial design. This design incorporated barrel and breech sections forged from CLARM series high-strength alloys obtained from Tecphy Corporation and machined by Manufacture de Forage. Part of the improvement of the design was implementing a laser alignment system for quick and accurate barrel alignment checks. This laser is also used to align the target assembly. This paper will detail the design changes incorporated into the installation, the testing process, and future direction of research for the new gun.

INTRODUCTION

Lawrence Livermore National Laboratory (LLNL), like other national laboratories, academic institutions, and military laboratories that do shock wave research, has a rich history in gun facilities to launch projectiles for producing shock waves [1-5]. One such facility at LLNL, the High Explosives Applications Facility (HEAF) [5], has recently replaced its 100 mm gun assembly with a new and improved design. The HEAF, originally brought on line in April of 1989 [3], was initially slated to use a 150 mm propellant driven single stage gas gun as the main launcher, with plans for using it with different size launch tubes as a two stage gun [4]. It appears that due to cost and design restrictions, a 100 mm barrel has been used in the place of this 150 mm barrel, strictly as a single stage propellant driven gas gun. The 150 mm barrel still remains on site in the facility, however, for future research if needed. And numerous studies have been performed using the original 100 mm gun assembly, even before the HEAF was constructed [1,2].

The 100 mm gun is used mainly for studies on initiation and detonation of high explosives [6,7]. The large 100 mm bore diameter of the gun makes it suitable for longer run distances to detonation when investigating low-pressure initiation or desire a long run to obtain a steady detonation wave in non-ideal explosives. The diagnostic most commonly used in these experiments incorporates manganin piezoresistive pressure gauges [8,9]. The data from these experiments is commonly used to obtain reaction rates for code development and validation.

Capabilities of the HEAF 100 mm gun facility include manganin pressure gauges, electromagnetic particle velocity gauging, 450 KeV flash x-ray (3 heads), as well as 5 beam Fabry Perot Laser Interferometry. Rotating mirror, streaking, and moderate high-speed color and monochromatic digital cameras are also available. Performing experiments in the elevated temperature range (to 250°C) and cooled to liquid nitrogen temperature are also not uncommon. A schematic drawing of the 100 mm gun assembly can be seen in Fig. 1.

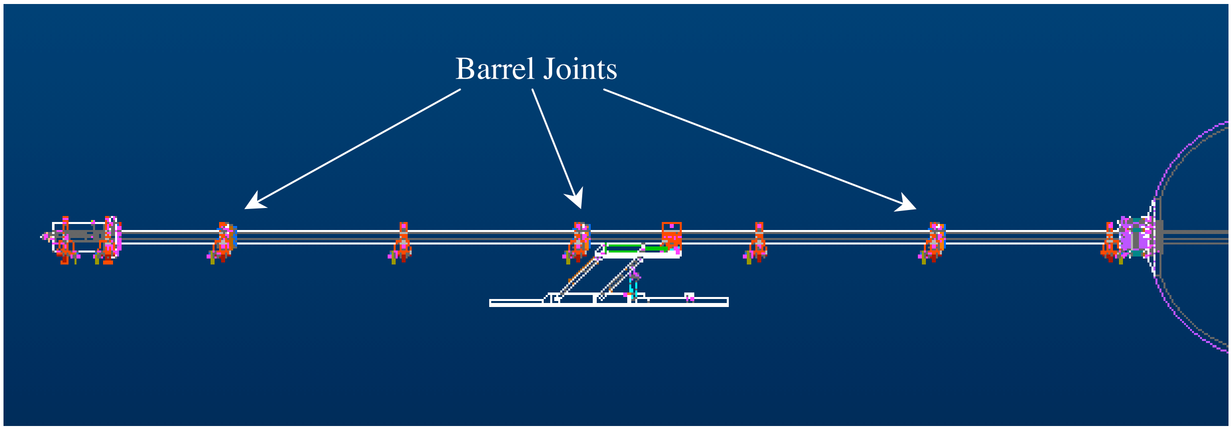

Fig.1. Schematic drawing of 100 mm gun assembly showing the breech assembly at left, barrel joints, collar supports, shock absorber damping system (center) and experiment tank (at right).

FACTORS INVOLVED IN REPLACEMENT

The barrel sections were in need of replacement due to excessive pitting on the inside of the barrels, especially at the joints. Deep honing was performed periodically for a time, but there became a point at which the honing was no longer able to renew the surface to even an acceptable level. Toward the end of the lifetime, projectiles would periodically break up in flight as seen in the flash x-ray photographs. Figure 2 shows a photograph of the removed barrel and breech sections along with the rail and support system after the barrel was removed.

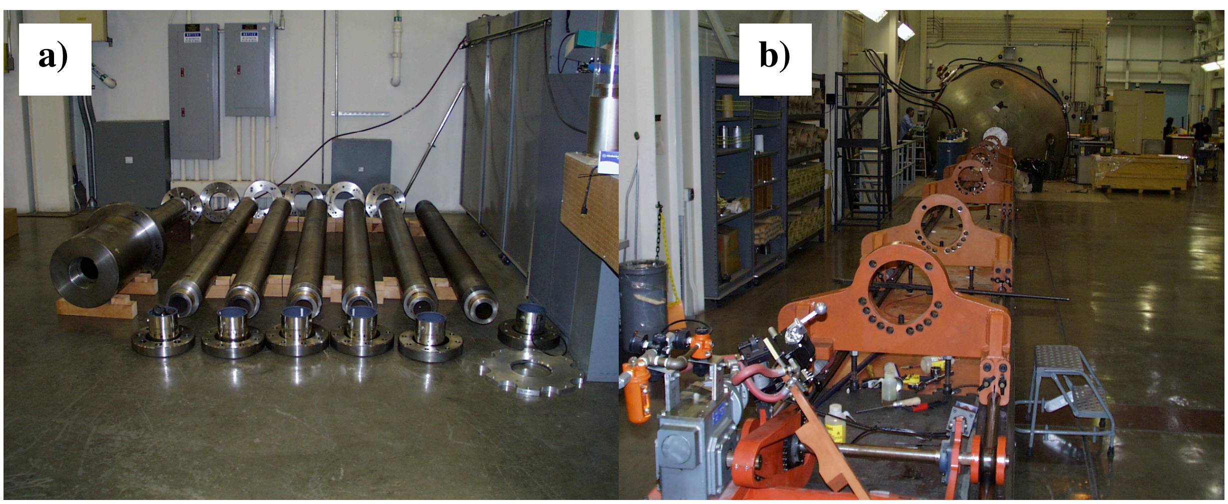

Fig. 2. Photographs of (a) old barrel and breech sections after being removed and (b) empty rails showing removal of barrel and breech sections. Note that the 6 barrel sections shown in Fig. 2(a) are reduced to 3 in the new design.

CHANGES / IMPROVEMENTS TO INITIAL DESIGN

The new 100mm gun assembly was designed by Thiot Ingenierie of France [10] and was based on improvements to the initial design. The new design incorporated barrel and breech sections forged from CLARM series high-strength alloys obtained from Tecphy [11] and machined by Manufacture de Forage [12], both companies located in France. The physical geometry of the new gun, except the breech, was maintained to utilize existing support structures; e.g. the rail bed and support collars. The maximum velocity obtainable is based on the maximum allowable breech pressure of 50,000 psi (345 MPa or 345 bar). The propellant used in the previous gun and subsequently in this gun is HPC-95, formerly made by Hercules but now produced by Alliant Teksystems.

As alluded to above, a number of things were changed in the redesign of the gun. The first includes using a proprietary French metal alloy series CLARM in the breech and barrel sections. The breech material and all the barrels, except the muzzle barrel section, are now alloy CLARM HB7. The muzzle barrel (barrel section entering the experiment tank) is made from alloy CLARM HBR. A higher allowable peak pressure is now obtainable for higher performance, an increase to 50 ksi (345 MPa or 345 bar) from the initial 40 ksi. A longer breech section accompanies this change, with 880 mm (34 inches) length as compared to the original 660 mm (26 inches) length. To coordinate with this longer length, a longer sting assembly to enable flame propagation through the length of the breech was used. The number of barrel sections was reduced to 3 by increasing the length of the muzzle and middle barrels to 220 inches (compared previously to 6 at 110 inches each). The breech bolts in the new breech were changed to ten M-42 threaded rods from the 16 original 1.5 inch socket head cap screws.

With all these changes though, a number of design parameters remained the same as the old design. The gun bore inner diameter, outer diameter, overall length of the gun barrels (1 section now as long as 2 original sections), and breech inner and outer diameter were kept the same. The forward support collars, collars used to support the gun on the rail bed, and collar bolts (after non-destructive evaluation) were retained from the previous gun. The shock absorber recoil mechanism also remained unchanged.

The question came up of the effect of the longer sting assembly and whether the flame from the primer powder ignition would adequately propagate down the length of the sting tube. A test of the new longer sting was performed to investigate the flame propagation through this initiation system. As a general description of the initiation system, it uses a 20 mm shell casing filled with 34 g of H870 primer powder which fires into the sting assembly (tube with annular holes) and ignites the HPC95 propellant loaded into a cardboard tube. The firing pin to initiate the 20 mm shell casing is actuated by a detonator that is set off by the capacitor discharge unit (CDU). Because the CDU is connected to the run-safe system with interlocks, this offers a safety feature of ensuring the gun is only fired after a sweep of the area is performed to ensure an unmanned area with a series of safety interlocks being actuated.

A summary of the sting test is included in Fig. 3 as a series of moderately high-speed Phantom 5 digital camera images (frames every 143 μs). There is an initial still frame at time t_0, and a sequence of images as the H870 primer powder flame front travels through the sting tube. For reference, the holes in the sting are 25.4 mm (1 inch) from center-to-center along the length. It can be seen that it takes roughly 400 μs for the flame to propagate down the length of the tube. The test confirms that the longer sting tube is sufficient to light the propellant charge (i.e. flame travels entire length of tube).

Part of the improvement of the design was implementing a laser alignment system for quick and accurate barrel alignment checks during the test series. This same laser is also used to align the target assembly before each shot. All of the components were obtained as off-the-shelf items from Hamar Laser Instruments [13]. The system consists of a model L-706 Laser with an A-510 2-axis, Self-centering Target equipped with an A-510A target Bore Adapter. Because the target is self-centering, the target is placed at the point of measurement through the barrel with the laser placed in the muzzle end of the barrel. An x-y reading is obtained where the laser shines on the target. The laser is then rotated 180 degrees and another reference point is obtained. From these two readings, a center of the target position can be correlated to the center of the muzzle end of the barrel. Generally this process is iterated several times adjusting the laser center to get an accurate reading of less than 250 μm (0.010 inch). The target can then be moved to another location throughout the barrel to obtain alignment information along the length. This equipment uses a R-355 Interface Communication Hardware with Read8 software to allow a laptop computer to store and plot all of the measurement information after each alignment procedure.

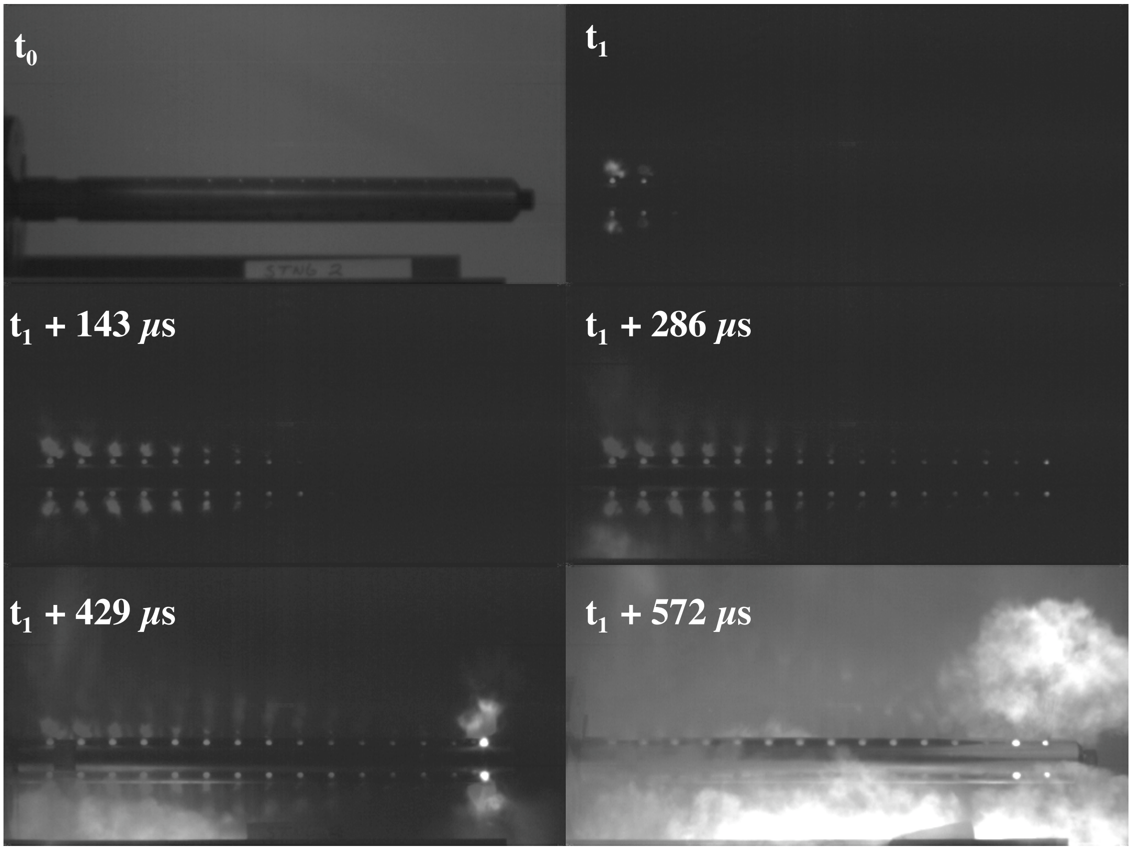

Fig. 3. A series of still images from a moderately high-speed digital camera showing an initial still frame at t_0, and a sequence of images as the H870 primer powder flame front travels through the sting tube. Images were obtained from a Phantom 5 High Speed Digital Camera running at 7000 frames per second with a 512x256 image and f-stop of 16 on a 16-100 mm zoom lens. The sting holes are at intervals of 25.4 mm (1 inch) from center to center along the length of the tube. The test confirms that the longer sting tube is sufficient to light the entire propellant charge.

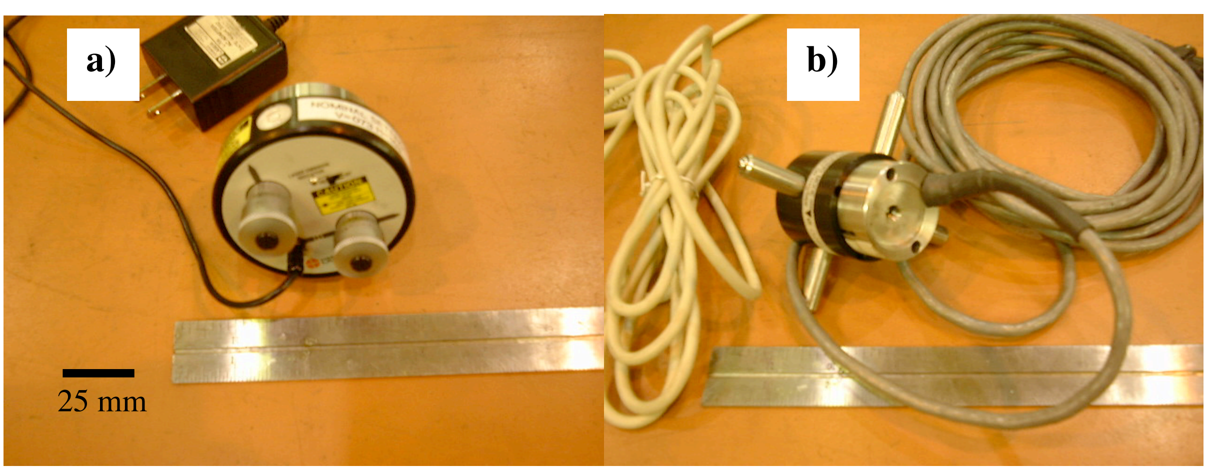

Fig. 4. Photographs showing (a) the Hamar L-706 laser unit and (b) the A-510 self-centering laser target. These units allow for quick and accurate checking of barrel alignment. The laser unit is also used for target alignment.

GUN TESTING AND EVALUATION

A series of gun tests were performed with the new gun using the two common sabot designs ("doorknob" and "Mod II"). The purpose of these tests was to validate the maximum allowable breech pressure versus projectile velocity and determine the velocity versus HPC-95 powder characteristics for the new 100 mm gun. Because of the two different projectile designs, the test series can be thought of as low velocity tests with the 1200 gram Mod II style projectile and low to high velocity tests with the 1000 gram doorknob style projectile. Figures 5 and 6 display the photographs of the sabot designs and target arrangements for these tests.

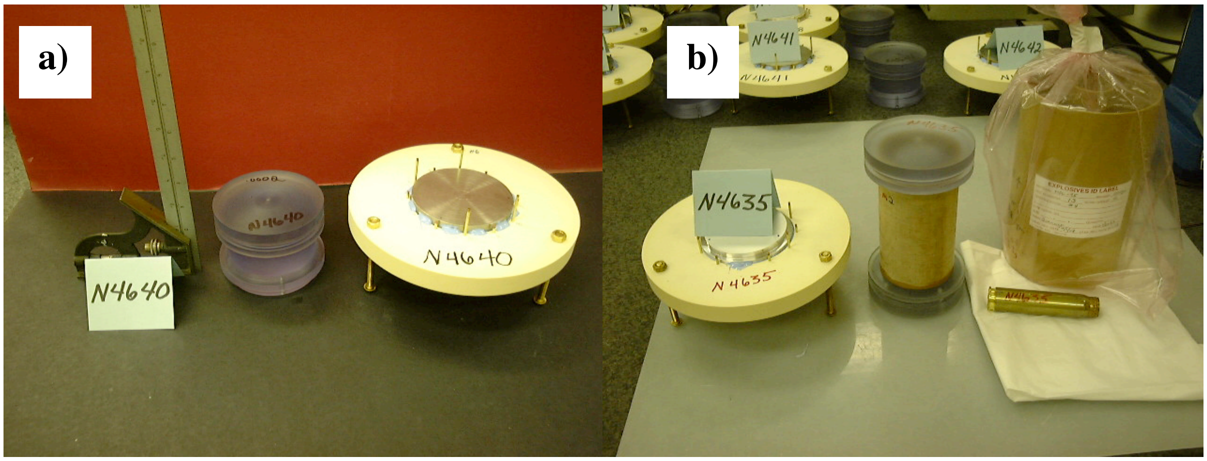

Fig. 5. Photographs showing (a) a "doorknob" sabot and target assembly for experiment N4640 and (b) a "Mod II" sabot (center) with target assembly (left), 20 mm primer powder shell casing (front right) and HPC-95 propellant charge in cardboard tube (at right).

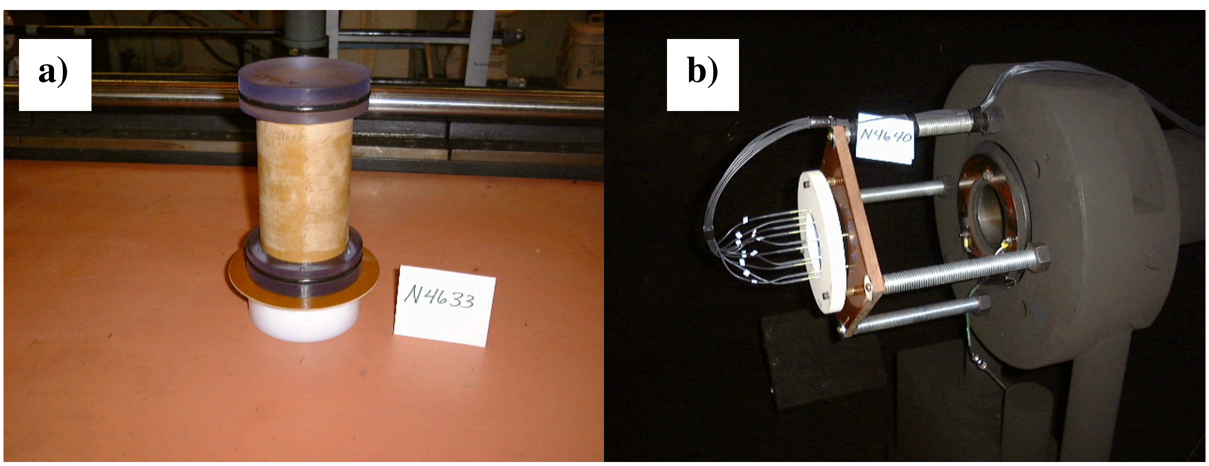

Fig. 6. Photographs showing (a) a "Mod II" sabot for shot N4633 with the O-ring seals, high-density polyethylene gas cup (bottom), and micarta shear disc installed along with (b) target assembly shown mounted on the fixture rods at the muzzle end of the barrel.

The breech pressure during the testing was maintained below the maximum allowable working pressure of 50 ksi (345 MPa or 345 bar). The gun is rated at the velocity corresponding to a 1000 g projectile and at a breech pressure equal to 50 ksi. The new breech volume is significantly larger and thus affects the corresponding pressure and velocity calibration.

A summary of the test shots for this series is included in Table I. Shown is the test number, projectile type and mass, HPC-95 propellant mass, measured velocity, and measured breech pressure. The projectile velocity was measured using piezoelectric crystal pins (as shown in Fig. 6 (b)) located flush with the target plate (to get tilt information) as well as at a standoff distance

The breech pressure is measured using a PCB Piezotronics [14] transducer system (model numbers: P119A11/003A03/402M143). A 1000 g projectile velocity of greater than or equal to 2.8 km/s was the ultimate goal, but as evident from Table I, the goal fell short of that at 2.675 km/s. A different high-performance propellant may be able to achieve the velocity goal of 2.8 km/s, however, testing of any new propellants has not yet started.

Table I. Summary of 100 mm gun testing results.

TEST	PROJECTILE / MASS	HPC 95 MASS (g)	MEASURED VELOCITY (km/s)	MEASURED BREECH PRESSURE (PSI)
Baseline*	Door Knob / 1000 g	0	0.1	-
N4633	Mod II / 1200.2 g	310	0.635	984.55
N4634	Mod II / 1199.8 g	310	0.646	1216.21
N4644	Mod II / 1200 g	310	0.666	965.25
N4646	Mod II / 1200 g	750	1.105	2972.97
N4614	Door Knob / 1000 g	1000	1.351	4247.4
N4635	Mod II / 1200 g	1100	1.401	5000
N4636	Door Knob / 1000 g	2000	2.03	16216
N4637	Door Knob / 1000 g	2750	2.44	321046
N4615	Door Knob / 1000 g	2600	2.448	29729.72
N4638	Door Knob / 1000 g	3000	2.577	40926.6
N4639	Door Knob / 1000 g	3200	2.624	44787.6
N4640	Door Knob / 1000 g	3380	2.675	49806.95

*Baseline data point from previous gun with no propellant charge and only 34 g H870 primer powder

A plot of the calibration points from the data in Table I is included in Fig. 7. This graph shows the projectile velocity obtained with varying HPC-95 powder loads. The calibration is plotted in this way with the equation for the powder mass solved for the desired velocity so as to allow the desired velocity to be entered into the equation and the desired powder load to be the calculated parameter. Note that the baseline point was added to this graph to indicate the 34 g primer charge that is used to ignite the propellant load and will generate a velocity of roughly 100 m/s by itself.

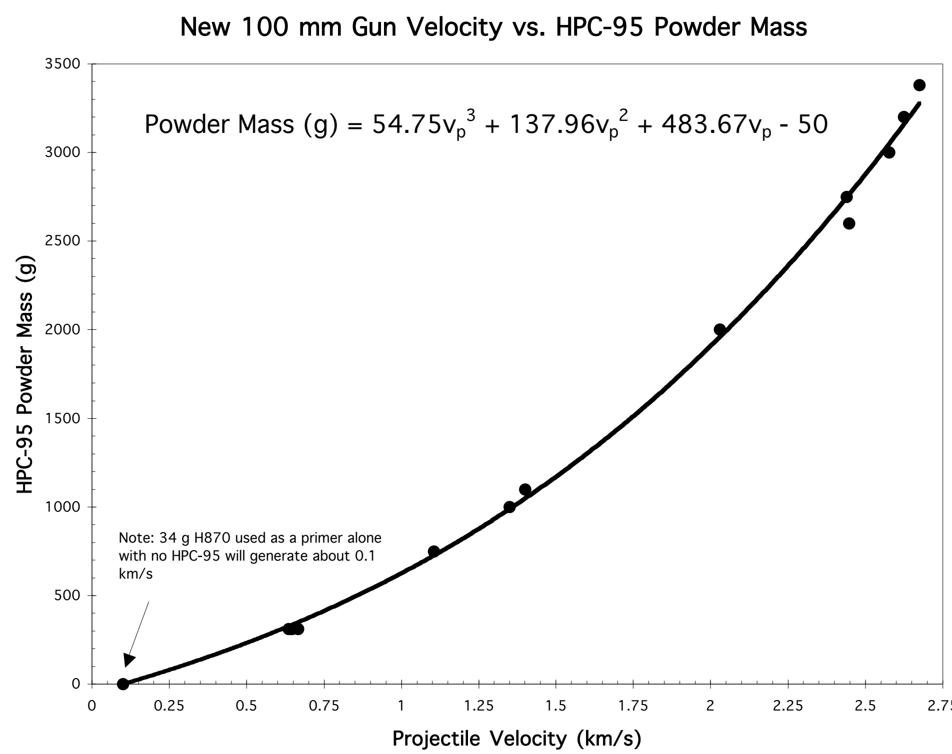

Fig. 7. Plot of calibration curve for the new 100 mm gun from initial testing results.

Figure 8 displays photographs of the newly installed 100 mm gun. Note the rather large experiment tank allowing the used of explosive targets for shock initiation and detonation studies. Experiments are currently being performed in the facility while the Engineering Safety Note for the gun is being written and reviewed [15].

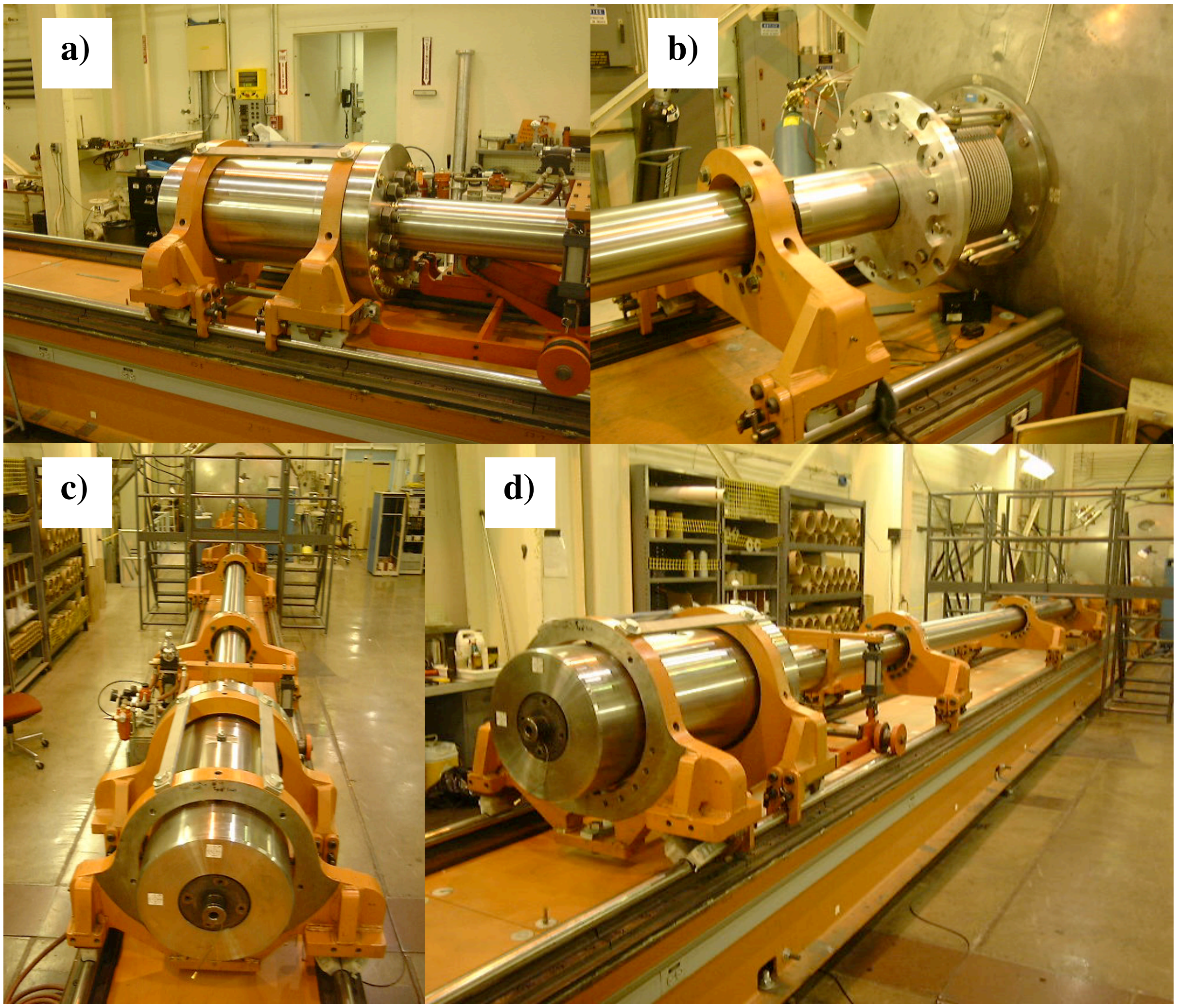

Fig. 8. Photographs showing (a) the installation of the new breech, (b) the location of the new barrel entrance into the experiment tank (c) view of the breech and barrel location from above and (d) side view of the breech and barrel installation.

CONCLUSION AND FUTURE DIRECTION

A new 100 mm gun assembly has been installed and tested at the Lawrence Livermore National Laboratory High Explosives Applications Facility. The gun facility is currently up and running with experiments being performed.

The future direction entails a continuation of the past research while incorporating the most advanced diagnostics available. Testing of performance propellants in the near future is desired, especially as the supply of HPC95 propellant becomes diminished.

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REFERENCES

1. D.L. Banner and C.A. Honodel, "Gun Facilities for One-dimentional Shock Wave Research at the Lawrence Livermore Laboratory," Proceedings of the 25th Aeroballistic Range Association, USN/NOL, October 1, 1974.
2. Leroy M. Erickson, "The 4 inch Light Gas Gun at LLL and it's Use for Detonation Physics Experiments," Proceedings of the 30th Aeroballistic Range Association, October 1979.
3. C. Honodel, "Lawrence Livermore National Laboratory's High-Explosives Application Facility—Nearing Completion," Proceedings of the 39th Meeting of the Aeroballistic Range Association, Albuquerque, NM, October 10-13, 1988.
4. F. Rienecker, C. Honodel, R. Waldron, E. Moor, S. Perfect, and R. Bast, "The LLNL 150-mm Equation-of-State Gun System," Proceedings of the 38th Meeting of the Aeroballistic Range Association, Tokyo, Japan, October 6-9, 1987.
5. Information on the High Explosives Applications Facility at Lawrence Livermore National Laboratory can be obtained on the internet at the following address: http://www-cms.llnl.gov/HEAF/
6. Paul A. Urtiew, Jerry W. Forbes, Craig M. Tarver, Kevin S. Vandersall, Frank Garcia, Daniel W. Greenwood, Peter C. Hsu, Jon L. Maienschein, "Shock Sensitivity of LX-04 with Delta Phase HMX at Elevated Temperatures," 13th APS Topical Conference on Shock Compression of Condensed Matter, July 20-25, 2003, Portland, Oregon, in press.
7. Kevin S. Vandersall, Jerry W. Forbes, Craig M. Tarver, Paul A. Urtiew, and Frank Garcia, "Re-Shock Experiments in LX-17 to Investigate Reacted Equation of State" Shock Compression of Condensed Matter-2001, Furnish, M. D., Thadhani, N. N., and Horie, Y, eds. CP-620, AIP Press, New York, (2002) 153-156.
8. Vantine, H. C., Erickson, L.M., and Janzen, J., " Hysteresis-Corrected Calibration of Manganin under Shock Loading," J. Appl. Phys., 51(4), pp. 1957-1962. (1980).
9. Vantine H., Chan J., Erickson L. M., Janzen J., Lee R. and Weingart R. C., "Precision Stress Measurements in Severe Shock-Wave Environments with Low Impedance Manganin Gauges," Rev. Sci. Instr., 51: 116-122, (1980).
10. Thiot Ingenierie, La Croix Blanche, 46130, Saint-Michel-Loubejou-France, www.chez.com/thiot
11. Tecphy, Avenue Jean Jaurès – 58160 Imphy, France.
12. Manufacture de Forage, B.P. 7, 8 Rue Du Garat, 42152, L'Horme, France.
13. Hamar Laser Instruments, Inc., 5 Ye Olde Road, Danbury, CT 06810, http://www.hamarlaser.com
14. PCB Piezotronics, 3425 Walden Avenue, Depew, New York 14043, http://www.pcb.com
15. LLNL Engineering Safety Note for 100 mm Gun END89-917 Rev. B, currently under review.